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## DESIGN OF FORMULA VARSITY RACE CAR SUSPENSION UPRIGHT

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**Abstract**—This paper presents the design of a suspension upright for Formula Varsity race car. CATIA V5 R16 CAD software was utilized to generate the 3D model of the final upright design. Aluminum alloy grade 6061-T6 was selected for the upright construction material due to its low density and good mechanical strength as well as wide availability in different sizes. Structural analysis using finite element method (FEM) was implemented to analyze the structural strength. CATIA V5 Generative Structural Analysis workbench as used in the analysis. Results from the structural analysis shows that the upright design has a factor of safety of 12.1, which theoretically proved that the structure is able to perform safely as per design requirement. A part from that, through utilization of aluminum alloy as the upright material, the weight of the component is able to reduce up to 57.5% compared to the upright used in 2010 UTeM Formula Varsity race car. Thus, the new upright design is able to provide the crucial weight saving needed for an efficient race car without compromising its structural strength and safety.

**Keywords**—suspension upright, design, Formula Varsity race car.

### I. INTRODUCTION

UTeM Formula Varsity is a racing competition where engineering students from various Malaysian higher learning institutions participated in the challenge to design, fabricate and race a working prototype of an open wheel, four-wheel formula style race car in real track condition. The event was organized by Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) [1].

For the upcoming 2012 event, a new team from Universiti Teknikal Malaysia Melaka was formed to design the new UTeM Formula Varsity race car. The aim is to reduce the weight of the overall car for better power to weight ratio compared to the previous 2010 UTeM race car. Among the targeted area for weight reduction is the vehicle suspension upright component. In this paper, the design improvement for the new UTeM upright component is discussed. Structural analysis to determine the performance of the new component is also highlighted to ensure that the weight saving gained in the end of this project will still be able to maintain the structural integrity needed for the component for safe and reliable operation.

### II. UPRIGHT DESIGN

Suspension upright is among the major component for a vehicle suspension system. The component serves as a provider for physical connection between the wheel and suspension links, as well as to provide mounting for the

brake caliper [2]. Uprights also play an important role in the performance of an open wheel racecar suspension system by transferring forces from the tire to the vehicle frame and shock assembly [3]. However, being part of the unsprung mass components, the upright weight can greatly give effect to the performance of the suspension, thus it is important to minimize its weight as it can reduce the load acting on the shock absorber assembly [4].

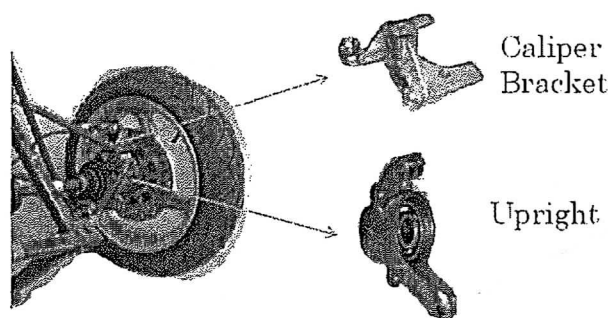


Figure 1. 2010 UTeM suspension system

As shown in Fig. 1 above, the 2010 UTeM's Formula Varsity race car suspension setup was based on the double wishbone suspension system. This system enabled high flexibility in tuning the suspension parameters such as chamber and toe setting for the tires. It can also be seen that the upright used for the suspension setup was selected from the Perodua Kancil wheel upright, and a modified Yamaha LC135 moped bike brake caliper bracket. This was assembled to the upright component to hold the brake caliper. Although the system proved very reliable and successful during the racing event, but it is relatively heavy due to combination of two components and difficulty of assembly.

Thus, to improve on the current suspension design, a new custom-design suspension upright was developed by combining both the upright component and the brake caliper bracket together. The design intent was that the new upright must be able to function as the link between the wheel and the suspension arms, and at the same time hold the brake caliper. Through combination of these two functions, the new custom-designed upright is able to be more compact and reduce the number of components on the suspension system, thus reduce the weight of the suspension system.

The new upright design was modeled in 3D using CATIA V5R16 CAD software. The use of 3D model in the design stage proved very useful in term of visualizing the final end product and regenerating new designs for optimization purpose. The CAD model was also useful especially to simulate the assembly of the upright at whole

suspension system, where mismatch errors occurred between the components can be quickly identified and solved. Fig. 2 and Fig. 3 show the new custom-design upright assembly for the double wishbone suspension system and the details of the new upright design.

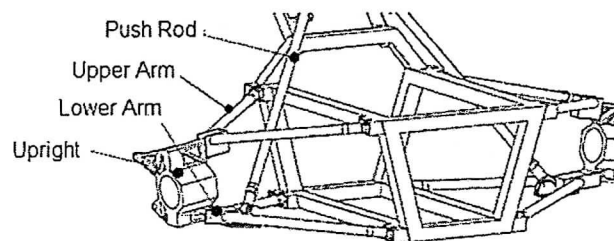


Figure 2. Suspension assembly using the new custom-design upright

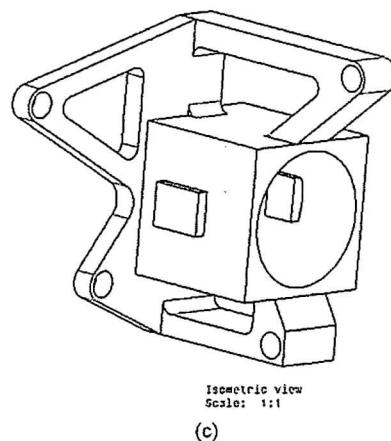


Figure 3. (a) Front view, (b) Side view, and (c) Isometric view of the new suspension upright

### III. LOAD ANALYSIS

The upright was analyzed by calculating each force acting on the suspension members. The force calculated are base on three scenarios that is, static force, lateral force and brake force. Each calculated value was then used in Finite Element Analysis to determine the structural strength of the upright.

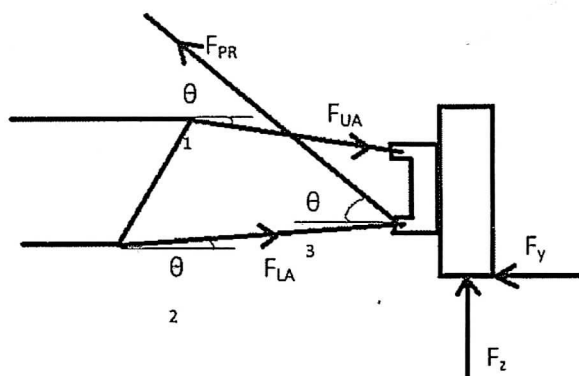
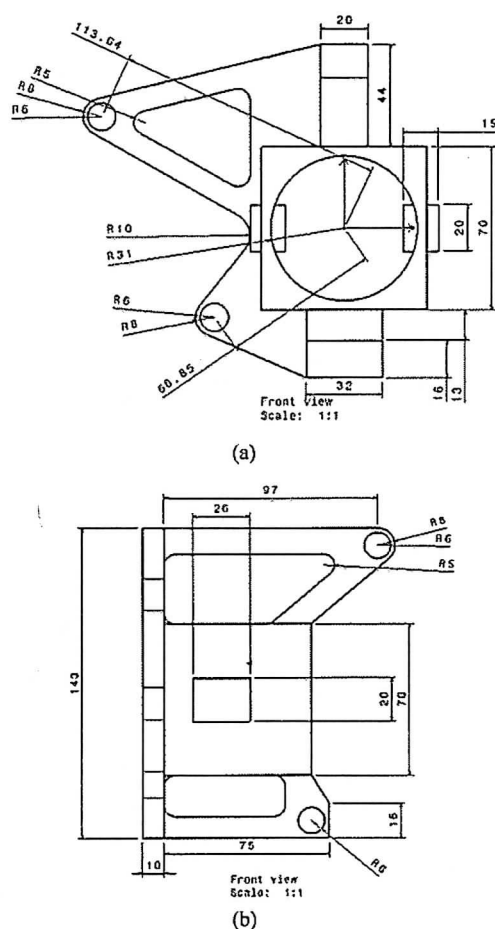


Figure 4. Free body diagram of rear suspension system

Fig. 4 shows the forces acting on the suspension system where,  $F_z$  is the forces acting on the tire in statics condition,  $F_y$  is the lateral force,  $F_{UA}$  the upper arm force,  $F_{LA}$  is the lower arm force and  $F_{pr}$  is the push rod force.

$F_z$  value is taken by weighing each four tires on a weighing scale. The experiment set up is shown on Fig. 5.

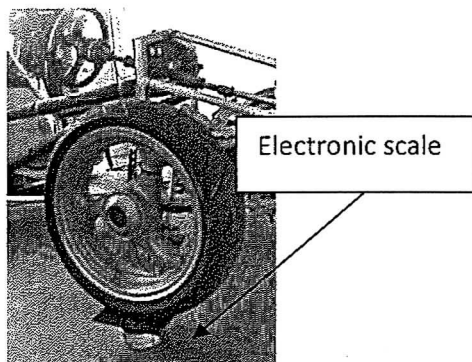


Figure 5. Electronic scale to weight the car

From experiment the value of mass acting on each tire are below

- Rear right tire = 65.67 kg
- Rear left tire = 60.01 kg

Since the right tire has the biggest value, the value will be used for analysis

Each angle also was calculated by measuring the suspension link setup to get its value.

For static case;

$$\begin{aligned}\theta_1 &= 14^\circ \\ \theta_2 &= 6.5^\circ \\ \theta_3 &= 51^\circ\end{aligned}$$

Static equation:

$$\begin{aligned}\Sigma F_z &= 0 \\ \Sigma F_y &= 0 \\ \Sigma M_A &= 0\end{aligned}$$

$$\uparrow F_z = 0$$

$$644.2227 - F_{UA} \sin 14 + F_{LA} \sin 6.5 + F_{PR} \sin 51 \\ 644.2227 - 0.2419 F_{UA} + 0.1132 F_{LA} + 0.7771 F_{PR} \\ \text{Equation 1]}$$

$$F_y = 0$$

$$-2000.5415 + F_{UA} \cos 14 + F_{LA} \cos 6.5 - F_{PR} \cos 51 \\ \text{Equation 2]}$$

$$M_A = 0$$

$$-(644.2227)(0.145) + (2000.5415)(0.1731) - \\ (F_{UA})(\sin 14)(0.275) + (F_{UA})(\cos 14)(0.19) \\ \text{Equation 3]}$$

Solve equation 3, and get the value  $F_{UA} = -2146.7015\text{N}$ ,  
 put value of  $F_{UA}$  into equation 1 and 2, then solve both equation

$$\begin{aligned}F_{LA} &= 3207.2123\text{N} \\ F_{PR} &= -1425.6089\text{N}\end{aligned}$$

For Lateral Force;

Force on right tire =  $mg$

$$\begin{aligned}&= (65.67)(9.81) \\ &= 644.2227\text{N}\end{aligned}$$

Lateral Force on tire,  $F_y$

- The mass selected for calculation is only at rear right tire because we assume that we assume the weight distributed as static case at each tire even under cornering
- The speed taken into calculation is equal to 10.42 m/s. (tested on track)
- Radius taken in calculation is equal to 12.7 m. (the smallest and hardest corner on event track)

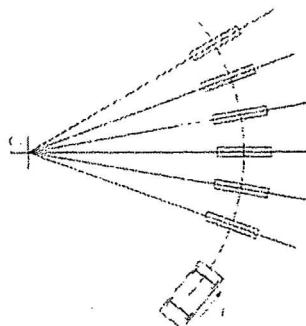


Figure 6. Rectangular roughness cornering [8]

Lateral force equation:

$$\begin{aligned}F_L &= \frac{mv^2}{r} \\ F_L &= \frac{(234)(10.42)^2}{12.7} \\ F_L &= 2000.5415\text{N}\end{aligned}$$

C. For braking force;

Master pump pressure;

$$F_1 = P_1 \times A$$

Where P is the pressure from master cylinder, F is the clamp load, A is equal to;  $\pi D^2 / 4$  and D is the diameter of caliper.

To measure the brake force, the relations between the master pump and the caliper piston is noted. The relations shows that the driver input force is applied to the master pump and transferred to the caliper piston the force is applied on the disc brake. Fig. 7 shows the diagram of the master pump and the caliper piston.

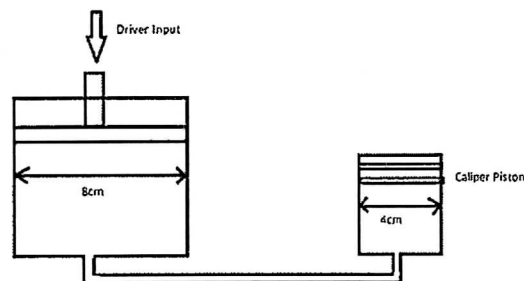


Figure 7. Relations between master pump and caliper piston



river Input = 823 N [9]  
 Pressure from master pump,  $P_1$

$$\frac{823}{\pi(0.08)^2/4}$$

163.73 kPa N

Caliper Force (clamping load),  $F_2$ ;

$$F_2 = P_1 \times A_2$$

where;

$A_2$  = caliper piston area

thus;

$$F_2 = (163.73k) \left( \frac{\pi(0.04)^2}{4} \right) \\ = 205.7492 \text{ N}$$

Disc Force,  $F_3$

Multiply by two because use 2 brake pads)

$$F_3 = 2(F_2)(\mu)$$

Assume the value of  $\mu$  (coefficient of friction) = 0.45

Good assumption for race car)

thus;

$$F_3 = 2(205.7492)(0.45) \\ = 185.1743 \text{ N}$$

Torque applied on disc brake,  $\tau$

Multiply by two because both side of the disc are applied  
 with the torque)

$$\tau = 2(F_3)(d)$$

Where:

$d$ : The distance between the center of the rotation and the  
 force to act at a point midway across the rotor face.

$$\tau = 2(185.1743)(0.18) \\ = 66.66 \text{ Nm}$$

#### IV. MATERIAL SELECTION

Due to no restriction for upright design material as stated in the Formula Varsity 2010 technical specifications, the possibility to engage on more advanced material with better lightweight and high strength properties was explored in this project [1]. In general, the application of aluminium alloys for racing car structural parts are widely accepted nowadays due to its low density and high mechanical strength but at a much higher cost compared to steels [5]. In this project, 6061-T6 grade Aluminium alloy was selected to be used for the suspension upright fabrication. Also known as Al 6061-T651 and ISO AlMg1SiCu, the six series aluminium alloy has relatively high strength, good workability, and high resistance to corrosion as well as excellent joining characteristics and good acceptance of applied coatings [6]. Moreover, the material is widely available in many

sizes. Table 1 below summarized the material properties of the aluminium 6061-T6 material selected in this project.

Table 1. Material Properties of aluminum 6061-T6 [7]

Material Properties	Value
Tensile strength (MPa)	310
Yield strength (MPa)	276
Shear strength (MPa)	207
Modulus of Elasticity (GPa)	68.9
Fatigue Strength (MPa)*	96.5
Density (kg/m <sup>3</sup> )	2700
Elongation at break (%) (typical 1.6mm thickness)	12
Composition:	
Aluminium, Al	95.8 - 98.6 %
Chromium, Cr	0.04 - 0.35 %
Copper, Cu	0.15 - 0.40%
Iron, Fe	≤ 0.70 %
Magnesium, Mg	0.80 - 1.20 %
Manganese, Mn	≤ 0.15 %
Silicon, Si	0.40 - 0.80 %
Titanium, Ti	≤ 0.15 %
Zinc, Zn	≤ 0.25 %
Aluminium, Al	≤ 0.15 %

#### V. STRUCTURAL ANALYSIS

The new upright design was later analyzed to determine its structural performance for the intended application. In order to assess the structural performance of the new upright design, structural analysis using CATIA V5 Generative Structural Analysis workbench was utilized. 3D model of the upright was imported as the geometry model for the finite element analysis. Automatic mesh option was used to generate the meshed model of the geometry. Fix boundary condition was selected at the upright main hub while loads were placed at the upright upper arm and lower arm joints.

After computing each force acting on the upright, CAD analysis use to determine the value of von misses stress and its displacement. Fig. 8 and Fig. 9 show the force distribution on the upright. Fig. 9 also shows the boundary that needed to be set to the upright before structure analysis. The type of boundary set is fixed and with no degree of freedom as the upright is considered as one rigid body.

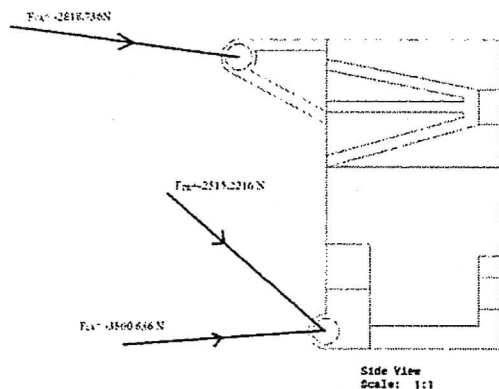


Figure 8. Forces Distribution On Upright

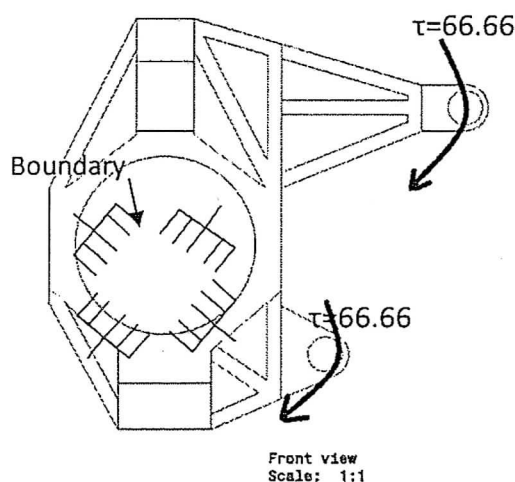


Figure 9. Torque applied on the caliper mounting and its boundary condition

## VI. RESULTS AND DISCUSSIONS

Results of the structural finite element modeling for the suspension upright are shown in Fig. 10 and Fig. 11 below.

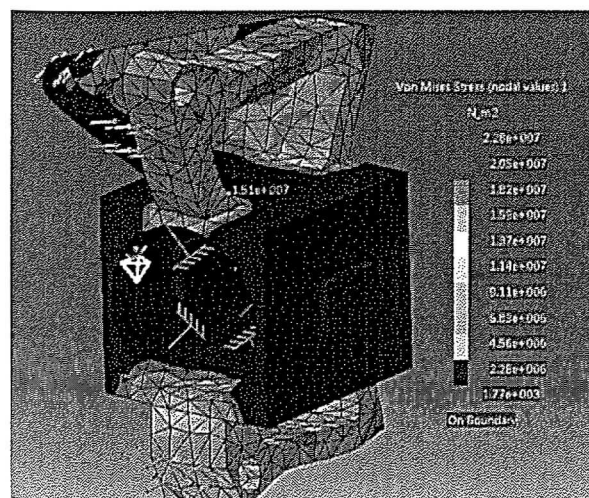


Figure 10. Stress distribution on the upright structure

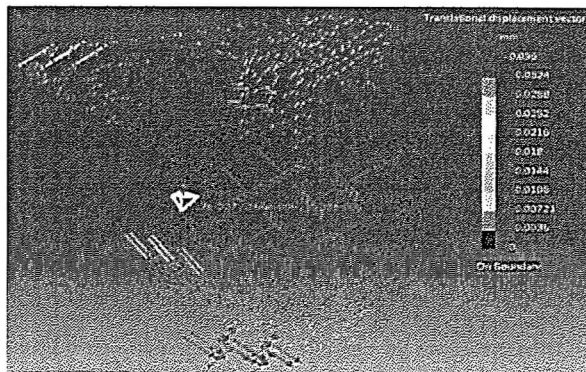


Figure 11. Displacement contour of the upright structure

Based on Fig. 10, the maximum stress occurred on the upright structure was found to be 22.8 MPa while from Fig. 11, it shows that the maximum displacement occurred was 0.0122 mm located at the top mounting point of the upright. By comparing the maximum stress value obtained with the material's maximum yield strength which is 276 MPa, the factor of safety for the design can be determined. Final analysis shows that the upright design has a factor of safety value of 12.1 which proven theoretically that the structure is safe for the intended application.

Theoretical load for the aluminium alloy upright design was also determined based on the 3D CAD model. The theoretical weight for the design was found to be 757 grams, which is approximately 57.5% lighter than the current upright installed on the 2010 UTeM Formula Varsity race car (the current upright weighs approximately 1779 grams). Thus, the new upright design is able to provide the crucial weight saving needed to build an efficient race car without compromising its structural strength and safety.

## VII. CONCLUSIONS

In conclusion, the aluminium alloy suspension upright designed for the new UTeM Formula Varsity race car was developed in this project. Based on simulation results, the upright structure has a factor of safety of 12.1 which shows it can withstand the load given without failure and is able to perform safely as per design requirement. Nevertheless, the feasibility of the aluminium alloy as the candidate for the upright material has to be further examined in terms of cost especially for the construction of budget racing cars.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] www.formulavarsity.utm.edu.my, (Accessed on December 2011).
- [2] A.J. Wong, Design and Optimization of Upright Assembly for Formula SAE Racecar, B.Eng Thesis, *University of Toronto*, 2007.
- [3] G. Erickson, M. Heath, B. Woods, D. Dolan, E. Henderson and J. Sears, Design and Manufacture of Titanium Formula SAE Uprights using Laser-Powder-Deposition, *SAE Technical Paper Series*, SAE International, 2004-01-3546, 2004.
- [4] D. E. Woods and B. A. Jawad, Numerical Design of Racecar Suspension Parameters, *SAE Technical Paper Series*, SAE International, 1999-01-2257, 1999.
- [5] D. Cambiaghi, M. Gadola and D. Vetturi. The Design, Manufacturing and Testing of an Aluminium Cast Upright, *SAE Technical Paper Series*, SAE International, Paper 983056, 1998.
- [6] <http://www.matweb.com>, (Accessed on December 2011).
- [7] Cambridge Engineering Selector (CES) EduPack software, Granta Design, 2010.
- [8] C. D. John(2009), "Suspension Geometry an Computation". The Open University, Great Britain.
- [9] A.H. Nurfaizy, The Design Of Light Weight Automotive Brake Pedal, MSc. Thesis, Faculty of Engineering and Computation, *Coventry University*, 2007.